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GRADUATE COLLEGE

RELATIONSHIP OF PERONEAL MUSCLE FATIGUE TO FUNCTIONAL ANKLE INSTABILITY

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

Master of Science

BY

SUBRINA V. LINSCOMB, CAPTAIN, USAF, BSC

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1996

RELATIONSHIP OF PERONEAL MUSCLE FATIGUE TO

FUNCTIONAL ANKLE INSTABILITY

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ABSTRACT

Background and Purpose. The purposes of this study were (1) to determine if peroneal muscle fatigue in extremities with functional ankle instability (FI) is significantly greater than fatigue in control extremities; and (2) to determine the reliability of testing the ankle evertors using the Kin-Com isokinetic dynamometer.

Subjects. Thirty subjects were tested. Eleven involved right subjects averaged 1.5 sprains and 9.0 episodes of "giving-way" in the 12 months prior to testing. Four involved left subjects averaged one sprain and 4.3 episodes of the ankle "giving-way" in the 12 months prior to testing. Fifteen control subjects had no history of ankle injury.

Methods. Fifty reciprocal inversion/eversion isokinetic contractions at 180°/s were performed bilaterally. The percent decline in peak torque (fatigue index) was calculated. Six control subjects were retested an average of 52.2 days later to test reliability.

Results. Two-way ANOVA revealed normality could not be assumed. The Wilcoxon signed-ranks test did not detect significant differences between the left and right extremities in each group, nor differences between the involved right and control groups. Reproducibility of the fatigue index variable was the least reliable.

Conclusion and Discussion. The results suggest fatigue, determined by fatigue index, may not be associated with FI. The data also suggest the fatigue index at 180°/s is not a reliable test for the ankle evertors.

CHAPTER I

INTRODUCTION

Ankle sprains have been cited in the literature as the most common injury in athletes (17, 19, 36, 52). Freeman (15) derived the term functional instability (FI) for the tendency of an ankle to "give-way". Functional instability following an ankle sprain has been documented to occur in 31-40% of all lateral ankle injuries (6, 15, 23). Tropp (56) found that athletes with FI are at higher risk for reinjury.

Since Freeman first described FI, there have been many studies with the purpose of correlating various clinical signs (i.e. peroneal muscle weakness, mechanical instability, proprioceptive deficits, and peroneal latency) with FI. Proprioceptive deficits are the most consistent finding present in ankles with FI (16, 23, 32, 33, 45, 58, 59).

There are inconsistencies in the literature associating FI with other clinical signs. Mechanical instability of the ankle had been studied in connection with FI. Two studies report significant mechanical instability in ankles with FI (22, 33), while three studies report no significant mechanical instability in ankles with FI (15, 45, 58). Muscle weakness has been reported in ankles with FI by some investigators (6, 59). Others have reported no detectable muscle weakness in ankles with FI (15, 32, 33, 45).

Peroneal latency had been studied in healthy ankles and in ankles with FI. Most studies report the action of the peroneals in terms of peroneal latency (22, 24, 41), or a stretch reflex (26), as responding too slowly to prevent an inversion ankle sprain. Konradsen and Raven (30), on the other hand, reported finding significantly different peroneal reaction times between groups with FI and groups without FI.

Even though FI has been shown to improve with the use of proprioceptive training (16, 18, 57, 58, 61), recurring injury with activity is still possible (57). Injury during activity has been related to muscle fatigue. Skiers injured during downhill skiing have described feeling extreme fatigue just before falling, stating the muscles would not prevent the fall that led to injury (12). Eriksson's (12) investigation of downhill skiers revealed Type I muscle fibers were being utilized the most with this activity, and the fibers were 75% depleted of glycogen by the end of a day of skiing. Mild muscle fatigue of the hamstrings has been shown to alter gait patterns in subjects with an anterior cruciate ligament deficient knee (60). These muscular changes have been hypothesized as possibly leading to injury.

Strengthening of the ankle dorsiflexors and peroneals have been described as the foundation of a rehabilitation program after an inversion ankle sprain (52). Johnson et al (25) found through autopsy studies of cadavers that the

peroneal longus, tibialis anterior (deep) and the tibialis anterior (superficial) are primarily composed of Type I muscle fibers. Type I muscle fibers atrophy quickly with a significant decrease in activity, as recorded through electromyographic changes, with disuse (14). Muscle atrophy of Type I muscle fibers has also been linked to muscle fatigue (12). The atrophy is combined with a drop in succinic dehydrogenase activity which reflects a decrease in the aerobic capacity of the muscle fibers (63).

It can be hypothesized that atrophy of the peroneals from disuse following an ankle injury, or glycogen depletion of the Type I muscle fibers with activity can lead to fatigue resulting in re-injury. The primary purpose of this study was to determine if there is a significant difference in peroneal muscle fatigue in extremities with FI compared to the uninvolved extremity and to controls.

The secondary purpose of this study is to examine test-retest reliability for ankle eversion on the Kinetic Communicator (Kin-Com) isokinetic dynamometer. No literature specific for ankle eversion on the Kin-Com currently exists.

CHAPTER II

LITERATURE REVIEW

In this literature review, the terms functional ankle instability (FI), muscle fatigue, and fatigue index will be defined. Clinical signs theorized to be associated with FI will be reviewed. It will be shown that decreased proprioception is the only clinical sign consistently linked to FI. Muscle fatigue and FI have never been tested for association. Support for the fatigue theory will be discussed.

ANKLE SPRAINS AND FUNCTIONAL INSTABILITY

Ankle sprains have been cited in the literature as the most common injury in athletes (17, 19, 36, 52). Garrick (17) studied a wide variety of high school sports for two years to ascertain the type and frequency of ankle injuries in athletes of similar ages. He examined 2,840 participants in 14 sports. A total of 1,176 injuries occurred with 14% involving the ankle. Eighty-five percent of the ankle injuries were sprains. Smith and Reischl (52) surveyed 84 varsity basketball players from five public high schools in Long Beach, California. Fifty-nine players (70%) reported a history of an ankle sprain. Twenty-six of the 59 players received professional care for their injuries. Eighty percent

of the subjects with a history of an ankle sprain had experienced multiple episodes. Maehlum and Daljord (36) investigated all sports related injuries treated at the largest emergency department in Oslo, Norway for one year. A total of 4,673 patients were treated for sports injuries during the study period. Of these, ankle sprains were the most common injury accounting for 16% of the injuries. Hardaker et al (19) reviewed injuries in dancers as athletes. In a three-year review of 211 injuries to dancers in the American Dance Festival, 38% of the injuries were located in the foot and ankle.

Freeman (15) derived the term functional instability (FI) for the complaint of the tendency for the foot to "give way". The incidence of FI following a lateral ankle sprain has been documented to occur in 31%-40% of all lateral ankle injuries (6, 15, 23).

Athletes with FI are at higher risk for recurrent sprains (56). There have been many studies focused on correlating various symptoms (i.e. peroneal muscle weakness, mechanical instability, proprioception deficits, peroneal latency etc.) with FI. The correlation is based upon the detection of abnormal physical signs in patients with the instability. This does not, however, show cause and effect.

Proprioception

Several studies have associated proprioceptive deficits with FI (13, 16, 23, 32, 33, 45, 57, 59). Three studies used a modified Romberg test to detect proprioceptive deficits (16, 23, 32). Freeman et al (16) suggest FI is due to motor incoordination consequent to articular de-afferentiation. They also report evidence that FI can often be prevented if patients are treated with coordination exercises. Their study looked at 85 patients with ligamentous injuries of the foot and ankle. The patients were treated either by immobilization, conventional physical therapy, or coordination exercises. The patients were tested for proprioceptive deficits and FI of the ankle. The incidence of proprioceptive deficits and FI was correlated with the treatment used. Proprioceptive deficits were determined using a modification of the Romberg's test. The patients were tested within three days of injury for the initial examination, and again six to fourteen months after injury for the follow-up examination. The patients stood on the injured side first with the eyes opened and closed. The sequence was repeated on the injured side. During the initial examination, proprioceptive deficits were objectively present in 25%, subjectively present in 9%, and absent in 16% of the patients. Forty-six of the 85 patients were seen for the follow-up examination. The remainder of the subjects could not be

assessed because of pain, weakness, or lack of movement. At the final follow-up when FI was correlated to the treatment used, 7% of the patients who had no significant pain, weakness, or lack of movement, and were treated with coordination exercises, had FI. For similar patients treated with other methods, the incidence of FI was 46%.

Itay et al (23) designed a study to evaluate the frequency and duration of residual symptoms following an inversion ankle sprain. They studied 90 consecutive patients with unilateral ankle sprains and a talar tilt angle of less than 10 degrees. The patients were examined using a modified Romberg test. At the one year follow-up, 31% of the patients had FI which presented as a feeling of "giving way" and a positive Romberg test.

Lentell et al (32) sought to determine the frequency of clinically detectable balance deficits in a population of ankles with FI. FI was defined as ankles which were chronically weaker, more painful, and/or less functional than the other ankle. Thirty-three subjects with FI were studied. The modified Romberg test was performed with the eyes open and closed. The involved ankle was compared with the uninvolved ankle. Fifty-five percent of the subjects demonstrated notable differences between sides. Of those, 94% had decreased balance on the side with FI.

Forkin et al (13) evaluated kinesthetic deficits in

gymnasts, which they felt was indicative of balance control. Eleven gymnasts with a history of more than one sprain of the lateral ankle participated in 30 passive movement trials on their injured and noninjured sides. A kinesthesiometer, a device used to measure perception of passive movement at the ankle joint, was used. The subjects also performed the one-legged balance test (modified Rhomberg test) with their eyes opened and with their eyes closed. The gymnasts ability to sense movement during passive ankle motion was significantly diminished on the injured side compared to the uninjured side. Sixty-three percent of the subjects, judged by independent observers blind to which side was injured, detected a balance deficit during standing on the injured side while the eyes were closed.

Passive motion sense using a moving platform was used by Lentell et al (33) to document the presence or absence of diminished proprioceptive sense in ankles with FI. FI was defined as ankles which were chronically weaker, more painful, and/or less functional than the uninvolved ankle. Forty-two subjects with unilateral, chronic ankle instability, were studied. The amount of passive movement before motion was sensed by the subject was noted and compared bilaterally. The amount of movement before motion was detected was significantly greater in the involved ankles than in the uninvolved ankles denoting diminished proprioceptive sense.

Ryan (45) used "time out of balance" to document dynamic control of the ankle (proprioception). Forty-nine subjects with unilateral FI were studied. All subjects had suffered at least six episodes of giving way within the past twelve months, or a total of at least three inversion sprains including two or more within the past 18 months. The time out of balance in unilateral stance was measured using The Uni-Axial Balance Evaluator. The involved extremity was compared with the uninvolved extremity. Significant differences were found between the extremities for the total time spent out of balance. The authors concluded the subjects spent more time out of balance on the involved leg indicating decreased proprioception.

Stabilometry has also been used to detect impaired proprioception by testing postural control in subjects with FI. Tropp et al (57) examined 444 players from 25 male soccer teams for past injuries, functional disorders, and mechanical instability of the ankle joints. Of those, 47 were randomly selected for stabilometry recordings to determine postural control. The players with FI (recurrent sprains or feeling of giving way) had significantly higher stabilometry values than players without FI indicating decreased postural control.

In another study, Tropp (59) used stabilometry to study 15 subjects with unilateral FI to investigate whether impaired postural control at single limb stance was present.

Functional instability was defined as recurrent sprains or giving way. Stabilometry values of the involved extremity were compared with the uninvolved extremity as well as with a control group without FI. No significant differences were found in the stabilometry values between the involved and the uninvolved extremities, however, the values for both the involved and the uninvolved legs of the FI subjects were significantly higher than the control ankles. This study suggests proprioception is decreased bilaterally in subjects with FI.

No studies were found refuting the presence of proprioception deficits in subjects with FI.

Mechanical Instability

Controversy exists in the literature as to whether mechanical instability of the ankle, sometimes referred to as anatomical instability, is associated with FI. Isakov's (22) study of peroneal latency found 100% of the eleven subjects with FI also had mechanical instability. FI was defined as recurrent sprains. Mechanical instability was assessed using the anterior drawer test.

Two additional studies used the anterior drawer to assess mechanical instability in ankles with FI, but did not find significant results (45, 58). Tropp (58) found only 36% of the ankles with FI were mechanically unstable. Ryan (45)

used the anterior drawer and the talar tilt (adduction of the talus) to assess mechanical instability. He graded the movement on a five point scale ranging from very hypomobile (Grade I) to very hypermobile (Grade V). An ankle was termed mechanically unstable if it received a Grade V or a grade at least two levels higher than the unaffected ankle on either test. Twenty-four percent of the ankles with FI were mechanically unstable.

Mechanical instability in ankles with FI has also been assessed with radiographic examination, but with inconsistent results. Lentell (33) studied standard anterior-posterior views along with stress views of ankles with FI. Statistical analysis showed a significantly greater amount of motion in the involved ankles compared with the uninvolved.

Freeman's (15) study of 42 patients with lateral ligament sprains and ruptures found no statistically significant antero-posterior instability of the talus (tested with stress radiographs). Freeman also did not find a statistically significant association between a persistent varus tilt of the talus and FI.

Muscle Weakness

Conflict regarding the presence or absence of muscle weakness in patients with FI also exists in the literature. Bosien et al (6) studied the incidence of disability following

ankle sprains in 148 college students. All of the subjects had been treated for an ankle sprain during their college career. One month prior to graduation, 113 students (76%) had a follow-up examination. Thirty seven subjects (33%) complained of FI which varied from recurrent sprains to instability of the ankle with walking. Thirty five of those subjects presented with various abnormal physical findings, including 23 subjects (66%) with peroneal muscle weakness as tested with manual muscle testing.

Freeman et al (15) studied sixty-two patients with lateral ligament injuries (42 with lateral ligament ruptures and 20 with isolated lateral ligament sprains). All of the patients with sprains and 28 of the patients with ruptures were treated with physical therapy. The remaining fourteen were sutured, immobilized, then treated with physical therapy. One year after injury, the incidence of FI (feeling of giving way) among patients who suffered simple sprains was very similar to that of those who had suffered ruptures. None of the patients had any detectable calf muscle weakness. The study did not specify how the muscle strength testing was done.

Isokinetic testing has been used to detect muscle weakness in ankles with FI. Tropp (59) supports the presence of peroneal muscle weakness in ankles with FI. In his study of 15 patients with unilateral FI (recurrent sprains or giving

way), he measured muscle torque for dorsiflexion and pronation with an isokinetic dynamometer. No significant differences were found between the involved and the uninvolved limbs for dorsiflexion. Significant differences between the two limbs for pronation were present with the involved being significantly weaker.

Lentell et al (32, 33) conducted two studies using an isokinetic dynamometer to determine if muscle weakness of the ankle evertors in ankles with FI was present. The studies looked at 33 and 42 subjects respectively with unilateral FI. They defined FI as being weaker, more painful, and/or less functional than the uninvolved ankle. Peak torque was measured at 30 and 0°/s in the first study and measured at 30, 90, 150, and 210°/s in the second study. No significant differences were noted between the involved and the uninvolved ankles at any of the speeds in either direction in both studies. The authors concluded muscle weakness of the ankle evertors was not present in ankles with FI.

Ryan's study (45) also supports the absence of peroneal muscle weakness in ankles with FI. Using an isokinetic dynamometer, he looked at 45 subjects with unilateral FI and measured muscle strength using the mean strength scores of the invertor and evertor muscles at 120 and 30°/s. Invertor muscle strength was significantly weaker on the involved side. No significant difference in the evertor

strength of the involved and the uninvolved ankles was noted.

Muscle Latency

The literature is inconsistent concerning the latency of the ankle muscles with landing from a jump or with sudden inversion of the ankle. Jones and Watt (26) studied whether or not the stretch reflex of the gastrocnemius and the tibialis anterior occurred too late to play a useful role in the arrest of a landing from a single step or jump to the ground. They measured muscular activity of the gastrocnemius and anterior tibialis muscles in eight healthy subjects after suddenly and unexpectedly dropping them from various heights above the ground. The largest part of electromyographyic (EMG) activity associated with landing deceleration was completed before the time required to generate a functionally effective stretch reflex in the muscles. The interval from the start of the fall to the first detectable surface EMG activity was independent of the height of the fall up to eight inches. The authors suggest the response of the muscles is formulated in and dispatched from the central nervous system.

Nawoczenski et al (41) studied 15 subjects with no history of ankle injury and 15 subjects with a unilateral inversion sprain. The subjects stood on a platform constructed so the individually triggered footplates dropped the ankle into 35 degrees of inversion. Electrodes were

placed over the peroneus longus muscle to determine when motor response began. Ninety-three percent of the subjects in the injured group responded more slowly with their injured ankle, however, the analysis of variance showed no significant difference between the two sides of either group.

Johnson and Johnson (24) did a similar study. They looked at 24 subjects divided into three groups: subjects with unilateral, lateral ankle sprains that were surgically repaired and rehabilitated; subjects with unilateral, lateral sprains that were rehabilitated without surgery; and subjects with normal ankles. The subjects stood on a platform constructed to produce inversion of either ankle. The subjects were randomly tested and the ankles were dropped into 35 degrees of inversion. The latency of the peroneal muscles was determined. No significant differences were found between the three groups, or between the affected versus the unaffected ankles for latency.

Two studies specifically tested peroneal latency in ankles with FI (22, 30). Isakov et al (22) tested the validity of the assumption that muscles controlling the ankle joint are no longer efficient with FI because of de-afferentiation of the articular mechanoreceptors caused by ligamentous and capsular damage. The study's design was similar to the previously discussed studies. Eleven healthy subjects and 11 subjects with a history of recurrent ankle

sprains were tested on a special apparatus that generated sudden inversion of the ankle. The subjects were unaware of the exact timing of the platform release. No differences in the peroneal latency was detected between the involved and uninvolved legs of the ankle sprain group, nor were there differences in the latency between the control and the sprain groups. The investigators concluded that the reflex contraction of the peroneal muscles due to a sudden inversion motion has no role in protecting the ankle joint during sprain, and that protection is mainly provided by the passive tissues.

Konradsen and Ravn (30) refute peroneal latency being the same in ankles with FI and normal ankles. They looked at active soccer players and cross-country runners. Fifteen subjects had severe FI (frequent sprains and/or giving way) and 15 were controls. The subjects were tested using a trapdoor capable of suddenly tilting the ankle 30 degrees into inversion. Surface electrodes recorded the response of the peroneal muscle group. The reaction time of the peroneals between the two groups was significantly different with the FI group having longer reaction times.

Summary

Ankle sprains have been cited as the most common injury in athletes. Functional instability, which has been

defined as "giving-way" or recurrent ankle sprains, is fairly common after a lateral ankle sprain. Proprioceptive deficits have consistently been linked to FI. All other clinical signs previously investigated have resulted in inconsistent results.

MUSCLE FATIGUE AND FUNCTIONAL INSTABILITY

Muscle fatigue can be defined as any reduction in the force generating capacity of a muscle (5). Muscle fatigue can lead to injury. In a study of downhill skiers by Eriksson (12), many of the skiers injured during downhill skiing reported experiencing extreme fatigue just before they fell, stating the muscles would not prevent the fall that led to the injury. To study this, Eriksson biopsied the thigh muscles of ten skiers in the morning before beginning to ski, during the middle of the day after a very long ski run, and at the end of the day. Eriksson found that mostly the Type I (slow twitch) muscle fibers, demonstrated by glycogen depletion, were being used with downhill skiing. When the total glycogen content was measured after a day of downhill skiing, up to 75% of the glycogen had been depleted. Eriksson hypothesized that fatigue of these muscles might explain why some skiers are injured after a fall at the end of their first day of skiing.

Muscle fatigue can also be illustrated by a reduction in motoneuron firing rates and a slowing of the muscle contractile speed (5). Van Lent et al (60) investigated the

influence of mild fatigue on muscle activity during walking and running after anterior cruciate ligament (ACL) rupture. Muscle activity was quantified through EMG parameters. Twelve subjects with an arthroscopically diagnosed ACL rupture and a control group of 15 healthy volunteers were tested. The subjects walked 10 minutes on a treadmill at 1.2m/s. Electromyographic surface electrodes were placed on the muscle bellies of the vastus lateralis, the vastus medialis, the biceps femoris, and the medial hamstring muscles. Mild fatigue did not affect the gait pattern of the control subjects but it did affect the pattern of patients with ACL ruptures. The mean EMG activity of the hamstrings as well as the activity time of the hamstrings and vastus medialis decreased. Decreased hamstring activity reduces the pull of the tibial posteriorly resulting in decreased knee stability, which can lead to re-injury.

Muscle atrophy has also been linked to muscle fatigue (12). Eriksson (12) looked at the muscle morphology of athletes with knee ligament injuries and found Type I fibers atrophied more than the Type II fibers in these athletes. This atrophy is combined with a drop in succinic dehydrogenase (SDH) activity. Succinic dehydrogenase is an oxidative enzyme in the muscle that has been selected to reflect the aerobic capacity of the muscle fibers (63). A decrease in SDH reflects a decrease in the aerobic capacity of the muscles

fibers which can lead to fatigue.

Fournier et al (14) studied adult female rats to determine if there are changes in the EMG activity of a slow or a fast muscle (labelled according to fiber composition) immobilized at different lengths. Electrodes were inserted and the rats were immobilized with the soleus (a slow muscle) and the medial gastrocnemius (a fast muscle) either in a shortened position, a lengthened position, or in neutral. The fiber composition of the soleus muscle is 86.4-89.0% Type I and 11-13.6% Type II; the medial gastrocnemius is 50.8% Type I and 49.2% Type II (25). Electromyographic readings were taken each hour for 24 consecutive hours on days 7, 17, and 28 after immobilization. A significant decrease in the EMG activity of the soleus muscle after seven days was noted in all three positions. The changes for the medial gastrocnemius were not as extreme. Atrophy, determined by muscle weight loss at the 28 day point, indicated the soleus atrophied to a greater extent than the medial gastrocnemius. The changes in EMG activity correlated with atrophy in the muscle.

Smith and Reischl (52) described strengthening of the ankle dorsiflexors and the peroneals as the foundation of a rehabilitation program after an inversion ankle sprain because these muscle groups are actively responsible for resisting an inversion/plantar flexion injury. The fiber composition of these muscles make a strong case to correlate fatigue with FI.

Johnson et al (25) performed an autopsy study on six cadavers to study the fiber composition of human muscles. All of the subjects had died suddenly and all were males. Muscle specimens were removed from the bodies within 24 hours of death. Superficial and deep muscle specimens were taken. Fiber types were made using myofibrillar ATPase preparations. The fibers were classified as either Type I or Type II. They did not differentiate between Type IIa and IIb. The peroneus longus, tibialis anterior (deep), and the tibialis anterior (superficial) were found to have 62.5%, 72.7%, and 73.4% of type I fibers, respectively. According to Fournier (14), significant EMG changes denoting atrophy can occur in less than one week in muscles with a high percentage of Type I fibers with disuse. Studies have shown Type I fibers atrophy significantly faster than Type II fibers (12, 14). Eriksson (12) linked atrophy in Type I fibers with fatigue through changes in SDH.

Fatigue Tests And Muscle Fiber Composition

Fatiguability of muscles can be examined by measuring the fatigue index. The fatigue index is defined by Thorstensson & Karlsson (53) as the mean decline in peak muscular force with 50 contractions and is expressed as a percent of the initial value. They averaged the peak torque values for the last three contractions and compared that value

to the average of the peak torque values for the initial three contractions. The fatigue index was used to investigate fatigue in human skeletal muscle with repeated fast maximal isokinetic contractions, and its relationship to the fiber composition of the contracting muscle. They used an isokinetic dynamometer to study the fatigue index of the knee extensors and muscle biopsies to study fiber composition of the vastus lateralis muscle of the quadriceps. The methodological error for the fatigue index determination on two separate days was 1.4%, and there was no systematic difference between the testing occasions. The development of fatigue in skeletal muscle performing repeated fast dynamic contractions with maximal effort was most marked in muscles with a high proportion of fast twitch fibers.

Hulen et al (21) sought to investigate how fiber composition is related to isometric endurance. Isometric endurance was timed at 50% of the subjects maximal voluntary isometric contraction (MVC) for the knee extensors. Muscle biopsies of the vastus lateralis muscle were also studied. Performance increased (longer endurance times) with a higher percentage of Type II fibers, however no relationship between MVC and fiber type composition was found.

Isokinetic Fatigue Testing

Isokinetic fatigue testing using the fatigue index was first used by Thorstensson and Karlsson (53) using an isokinetic dynamometer. Since that study, there have been other studies to determine the validity and reliability of testing fatigue using isokinetic dynamometers.

Patton et al (42) conducted a study to determine the shape of isokinetic fatigue curves and to determine if those curves are similar for both sexes at different strength levels. They operationally defined fatigue as occurring at the first decile in which mean torque production was significantly different from the initial torque produced. Exhaustion was defined as the inability of the subject to perform another contraction. Elbow flexion was tested at 60°/s to the point of exhaustion. The data was presented in deciles (10% units) of the total time. The overall trend in the fatigue curve analysis demonstrated significant linear and quadratic components. The subjects reached fatigue according to the operational definition at the 30% time mark. The torque produced on that trial ranged from 54% to 69% of the initial torque produced. This study supports the use of 50% of initial peak torque test described in the instruction manual for the Cybex II dynamometer (4). The fatigue patterns for men and women were similar.

Barnes' (2) study was designed to compare the shape of

isokinetic fatigue curves at four preselected contraction velocities. He studied 25 men and generated fatigue curves for the knee extensors at 60, 120, 150, and 300°/s. Each subject performed 10 maximal knee extensions at the four test velocities in random order. Linear regression analysis showed a highly significant linear trend for the fatigue curves at all test velocities. Torque production in the final trial was significantly different from torque production in the initial trial, thus the 10-contraction test was considered to be fatiguing in nature. The rate of fatigue did not differ regardless of the test speed for any of the subjects.

Burdett and Swearingen (7) did a study to determine the reliability of measuring the following parameters for the quadriceps and hamstrings on an isokinetic dynamometer: 1) peak torque, 2) various work measurements, 3) torque acceleration energy, 4) average power, 5) work ratio, and 6) the number of contractions until strength fell to 50% of initial strength. Reliability was determined at 180 and 240°/s. Thirty-six healthy subjects were tested at four separate sites by a different tester utilizing a standard data collection protocol. Gravity-corrected data for twenty-five consecutive quadriceps and hamstrings contractions at either 180 or 240°/s were collected. Peak torque and peak torque acceleration energy were defined as the maximum values of these parameters which occurred in the first five

contractions. Work ratio was defined as the ratio of the work done during contractions 21 through 25 to the work done during the first five contractions (similar to the fatigue index test). The test ended upon completion of 25 contractions and the decline of the torque to 50% of the initial maximum value. Peak torque, all work measurements, and the average power were very reliably measured at both test speeds for the quadriceps. Reliability of these measurements for the hamstrings were not as high, but were above the 0.8 level needed for a clinically reliable test. Reliability for torque acceleration energy and the work ratio was generally less than 0.8. The reliability of the number of contractions until 50% of initial strength was good at 180°/s but was less than 0.8 at 240°/s. Tests at 180°/s tended to have smaller differences between them.

Sinacore et al (51) pointed out flaws in the above mentioned tests. They state a methodological flaw exists because the endpoints of the tests highly depend on the individual's level of initial torque output. They also point out a theoretical flaw in that individuals with initially high torque outputs will appear more fatigued than individuals with moderate or lower initial peak torque outputs. This flaw was proven by Patton et al (42). Because of these flaws, Sinacore et al (51) went on to describe and test recovery from a 1-minute bout of fatiguing isokinetic exercise testing the quadriceps femoris muscle. The subjects performed 50

repeated, maximal isokinetic knee extensions at 180°/s at a pace of 50 extensions per minute. Recovery was assessed by each subject performing a single maximal knee extension every 30 seconds for four minutes of recovery. The percent decline in torque after one minute, and at every 30-second interval of recovery was calculated and expressed as a percentage of the initial peak torque. They found the intraclass correlation coefficients (ICC) for the recovery of peak torque test high, ranging from 0.87 at the first 30-second interval of recovery to 0.67 at the 2 1/2 minutes of recovery. They also found the initial peak torque at 180°/s and the percentage of decline in torque were highly reproducible (ICC = 0.98) over a five day interval (with the time of day and diet controlled). Sinacore validated the fatigue index test as well as described an additional reliable fatigue recovery test.

Leslie et al (34) tested the reliability of isokinetic torque values for ankle invertors and evertors in healthy subjects. Sixteen subjects, randomly assigned to one of two groups, were tested at 30 and 120°/s with the ankle at zero and 20 degrees of plantarflexion. One group used range of motion targets during testing, while the other group did not. Five complete cycles of inversion and eversion were performed at each test speed and each ankle position with a one minute rest period between trials and tests. The tests were performed bilaterally, and the complete series of tests were

repeated at least 24 hours later. Test-retest reliability for inversion/eversion torque was greater using the ROM targets. The inversion peak torque was significantly greater than eversion peak torque in all but two tests.

SUMMARY

Functional ankle instability was initially defined as "the feeling of giving way". Recurrent sprains have been added to the operational definition of FI. Controversy in the different theories thought to contribute to FI exists in the literature. Muscle fatigue has been linked to injury, and is associated with muscle atrophy. Muscle atrophy occurs very quickly in Type I muscle fibers. The ankle dorsiflexors and evertors, which are the primary muscles thought to prevent to motions of an inversion ankle sprain, are primarily composed of Type I fibers. Consequently, it can be hypothesized that atrophy resulting from disuse following an ankle sprain, or glycogen depletion of the Type I fibers with activity, can lead to fatigue resulting in reinjury.

The primary purpose of this study is to determine if there is a significant difference in peroneal muscle fatigue in extremities with FI compared to the uninvolved extremity and to controls. The operational definition for FI is a history of recurrent ankle sprains or the ankle "giving way". Significant peroneal muscle fatigue in ankles with FI could

indicate the need to incorporate endurance training as a routine part of rehabilitation for patients diagnosed with lateral ankle sprains. Rehabilitation protocols for ankle sprains include modalities, compression, range of motion exercises, strengthening, proprioception, and functional rehabilitation, but omit endurance training (10, 28, 35, 43, 46, 48, 54).

The secondary purpose of this study is to examine test-retest reliability for ankle eversion on the Kin-Com, and to determine significant differences between groups with and without FI for peak torque, time to complete the fatigue test, eversion range of motion, and mean peak force. Work and power data will not be analyzed. It has been shown that peak torque represents work (40, 65) and power (65), and analysis of these variables offers little additional information.

CHAPTER III

METHODS

SUBJECTS

Subjects were recruited from the University of Oklahoma Health Sciences Center and the Oklahoma Center for Athletes in Oklahoma City, Oklahoma. A total of 34 subjects volunteered to participate. The control group consisted of ten females and six males. This group had no history of ankle injury, foot or lower leg fractures. The injured group consisted of nine females and nine males. These subjects had a condition of unilateral, chronic ankle instability. The criteria used to meet this definition included: 1) a history of a unilateral, lateral ankle sprain; 2) a history of two or more episodes of "giving way" and/or recurrent sprains within the past 12 months; and 3) not having had a sprain within four weeks of being tested.

Data for one control subject and three subjects in the injured group were not analyzed due to the subject's inability to complete the required task. Thirty subjects, 15 controls and 15 injured, were analyzed. The injured group was further divided according to which extremity was injured. The descriptive statistics of the subjects are given in Table 1.

All subjects were informed in writing about the

purpose of the study, known risks, and the right to terminate participation at will. All subjects signed a consent form approved by the Institutional Review Board at the University of Oklahoma Health Sciences Center (Appendix A).

TABLE 1. DESCRIPTIVE STATISTICS OF AGE, GENDER, AND NUMBER OF INJURIES BY INJURY GROUP

	CONTROL (n = 15)	**INJURED RIGHT (n = 11)**	**INJURED LEFT (n = 4)**
AGE (Years)	31.4 +/- 6.7	28.8 +/- 10.3	33.0 +/- 10.6
MALES	6	6	2
FEMALES	9	5	2
NUMBER SPRAINS PAST 12 MONTHS	Not Applicable	1.6 +/- 1.4	1.0 +/- 1.2
NUMBER "GIVE-WAY" PAST 12 MONTHS	Not Applicable	9.0 +/- 7.2	4.3 +/- 1.3

STUDY DESIGN

Initially, a three factor design (group by involved side, difference between left and right sides, and order of presentation), with counterbalancing of the order of presentation within each group, was used. Preliminary analysis showed no differences in the order of presentation. The study proceeded as a two factor analysis (group by involved side and difference between left and right sides)

with repeated measures on side.

INSTRUMENTATION

The measuring instrument was the Kinetic Communicator (Kin-Com) isokinetic dynamometer, model 125AP (Chattecx, Hixson, TN). The performance of the Kin-Com for measuring force, angle and velocity has been proven reliable. Mayhew et al (38) tested the performance of the Kin-Com for measurements of force, angle, and velocity by comparing the Kin-Com recordings to external recordings for known weights, angles, and user-set velocities. Testing was performed on two different days. For all conditions, the coefficient of determination for the force, angle, and velocity measurements was above 0.99. The intraclass correlation coefficient for between day comparisons for all measurements was also above 0.99.

The Kin-Com has also been proven reliable for measuring peak torque. Arnold and Perrin (1) established the Kin-Com's reliability for measuring peak torque and angle specific torque for knee extension at 30, 60, and 75°/s over two test periods 48 hours apart. Wilhite (62) proved the Kin-Com reliable for measuring peak torque and average torque of healthy right quadriceps over three consecutive weekly sessions at 60, 120, and 180°/s in different orders except when the 180°/s test is performed first.

Harding et al (20) tested the reliability of a reciprocal test protocol on the Kin-Com. They found the Kin-Com to be highly reliable for isokinetic leg strength measurements (knee extensors and flexors). There have not, however, been any studies specific to ankle inversion/eversion on the Kin-Com.

PROCEDURES

All of the subjects completed a questionnaire to collect demographic data (Appendix B). The subjects then performed a five-minute warm up on a Monarch stationary bicycle by cycling at a comfortable pace with the resistance set to comfort. The subjects were then ready to perform the fatigue test. The start side for fatigue testing was determined by the subjects choosing a card with either left or right written on it. There was an equal number of left and right cards in the pile, and the pulled cards were not replaced.

The Kin-com was set up for the appropriate extremity utilizing the preset settings for ankle inversion/eversion (29). Adjustments to the preset position were made so that each subject was seated in a semi-reclined position with the hip on the side being tested flexed between 75 and 80 degrees, the knee flexed (31, 47, 48) to 100 degrees, and the ankle slightly plantar flexed 5 to 10 degrees (8). The test leg was

stabilized at the proximal calf with the universal stabilizer and straps. The foot and ankle were secured into the ankle inversion/eversion attachment with straps. All subjects wore low-top athletic shoes and socks. The trunk, hips, and opposite thigh were also stabilized with straps (Fig 1).

The subject's range of motion (ROM) was set within the protective stops (11). The subjects were instructed to lie back in the chair with their arms folded across their chest for the test. The test motions of inversion/eversion were explained to the patient. The subjects performed five submaximal, concentric, reciprocal contractions at 180°/s (7) to familiarize them with the machine. The subjects were then allowed to rest for one minute before performing the fatigue test. During the rest, any necessary adjustments for comfort were made, and the subjects were given further instructions for the fatigue test. They were instructed to perform the same motions as in the warm-up as hard and as fast as possible until instructed to stop. The subjects were not told the number of repetitions required for the test. They were told they could stop exercising before instructed to do so if they began to experience pain, or were too fatigued to continue. The subjects then performed the maximal, concentric, reciprocal contractions at 180°/s. The subjects repeated the contractions until they completed 50 repetitions, or voluntarily stop exercising. The subjects received verbal

encouragement throughout the test. The same procedure was followed on the opposite ankle. The subjects were not allowed to watch the computer screen during testing.

Six of the control subjects returned for retesting an average of 52.5 days (range 29 days to 127 days) later for test-retest reliability. The protocol was followed exactly as previously described. The order of testing for the extremities was the same as the first test. The time of day for testing was consistent within one hour for all but two subjects.

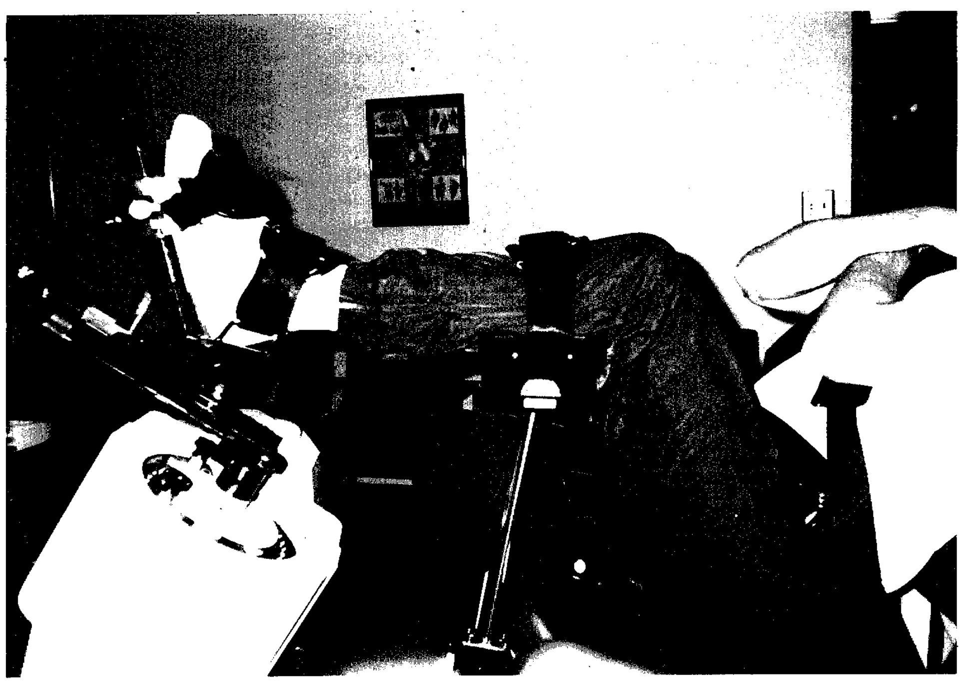

Figure 1. Patient positioning on the Kin-Com.

DATA ANALYSIS

Eversion data was collected from the Kin-Com software package version 5.03. The peak torque, mean peak force, and range of motion were collected from the summary printout. The "time" to perform the task was determined by putting a marker at the end of the last contraction and reading off the time in seconds.

Fatigue index was calculated by dividing the average of the peak torque values for the last three contraction by the average peak torque for the first three contractions (53). This value was multiplied by 100 to get a percent value for fatigue. The percent value was subtracted from 100 to show the percent change, and reveal if the change was positive or negative.

The following ten variables were analyzed for test-retest reliability: 1) fatigue index left; 2) fatigue index right; 3) peak torque left; 4) peak torque right; 5) time to complete test left; 6) time to complete test right; 7) eversion ROM left; 8) eversion ROM right; 9) mean peak force left; and 10) mean peak force right. For each variable, the test-retest values were examined for differences in the means for the first and second tests. The values of the second test were subtracted from the values of the first test for each variable, and averaged across the six subjects to get the "re-test" value. The retest variable tells if the values of the

second tests tend to be higher or lower than values of the first tests. For each variable, the distribution of the absolute values of the differences in the retest values were also examined. The absolute value gives the real difference between the values of the first and second tests, and reveals how close the second test was to the first test.

The Statistical Analysis System (SAS) software program was used for data analysis. The summary statistics (means, medians, standard deviations, maximums, and minimums) for all variables were computed. General linear model (GLM) procedures were used to evaluate differences between measures of the different variables between the three groups. Initially, two-way analysis of variance (ANOVA) was used to determine if there were significant differences between the groups, and/or between the left and right sides within subjects for fatigue index, peak torque, time to complete the task, eversion ROM, and mean peak force. Also, three-way ANOVA was used to determine significant differences between the groups, the genders, and between the left and right sides within subjects for fatigue index. Possible departure from normality was observed for some of the variables. For those analyses where many F values were less than one, the Wilcoxon signed-ranks test was used to examine differences between the right and left sides nonparametrically. The paired t-Test was used to examine the differences between the right and left

sides for the variable peak torque. The Mann-Whitney U test was used to determine differences between the left extremity of the injured right and control groups.

Spearman Correlation Coefficients were used to measure the strength of association between the variables for the left and right extremities of the control and the involved right groups. The involved left group was not analyzed due to the small sample size (N=4).

CHAPTER IV

RESULTS

TEST-RETEST RELIABILITY

The summary statistics for the retest values are given in Table 2. The mean and median differences between the first and second tests were greatest in the variables fatigue index left and fatigue index right. The same two variables along with the mean peak force right variable had the largest standard deviations. The variables with negative values show the value of the second test tended to be lower than the value of the first test. None of the differences, positive or negative, were significantly different from zero. The Wilcoxon signed-ranks procedure was used for this test. The smallest p-value was for the time left variable ($p = 0.156$).

Mean peak force left had the smallest mean and median difference between the test sessions, but had a fairly large standard deviation. Peak torque left, peak torque right, and eversion ROM right had the smallest standard deviations.

The summary statistics for the absolute values of the differences between the first and second tests are given in Table 3. The mean and median differences between the first and second tests were greatest in the variables fatigue index left, fatigue index right, and mean peak force right. The variables with the largest standard deviations were the

fatigue index left and fatigue index right. The same two variables had the average largest difference between the two test sessions (max variable). The smallest differences (min variable) between the two test sessions were seen in the variables mean peak force left, time right, and peak torque right.

TABLE 2. SUMMARY STATISTICS FOR RETEST VARIABLES (N = 6)

VARIABLE	MEAN	MEDIAN	STD	MAX	MIN
FATIGUE INDEX LEFT (% CHANGE)	-6.11	-7.43	17.11	13.22	-33.97
FATIGUE INDEX RIGHT (% CHANGE)	7.56	5.38	14.18	29.27	-10.54
PEAK TORQUE LEFT (Nm)	-1.60	-2.70	4.76	4.20	-7.40
PEAK TORQUE RIGHT (Nm)	2.17	3.50	3.44	4.80	-4.00
TIME LEFT (Seconds)	4.47	5.20	5.34	11.02	-3.71
TIME RIGHT (Seconds)	3.74	0.51	6.67	15.79	-1.42
EVERSION ROM LEFT (Degrees)	0.83	3.00	8.04	9.00	-9.00
EVERSION ROM RIGHT (Degrees)	-1.83	-3.00	4.17	4.00	-6.00
FORCE LEFT (Newtons)	-0.39	0.40	7.13	9.34	-12.77
FORCE RIGHT (Newtons)	-1.34	-1.80	11.48	12.18	-17.98

Abbreviations
STD - Standard Deviation
Max - Maximum Difference Between Test Sessions
Min - Minimum Difference Between Test Sessions
ROM - Range of Motion
Nm - Newton-meters

TABLE 3. SUMMARY STATISTICS FOR ABSOLUTE VARIABLES (N = 6)

VARIABLE	MEAN	MEDIAN	STD	MAX	MIN
FATIGUE INDEX LEFT (% CHANGE)	13.89	10.93	10.29	33.97	4.17
FATIGUE INDEX RIGHT (% CHANGE)	11.66	8.98	10.32	29.27	1.75
PEAK TORQUE LEFT (Nm)	4.33	4.10	1.78	7.40	2.20
PEAK TORQUE RIGHT (Nm)	3.50	4.30	1.67	4.80	0.60
TIME LEFT (Seconds)	5.71	5.69	3.67	11.02	1.41
TIME RIGHT (Seconds)	4.31	1.23	6.24	15.79	0.03
EVERSION ROM LEFT (Degrees)	6.83	8.50	3.06	9.00	2.00
EVERSION ROM RIGHT (Degrees)	3.83	4.50	1.94	6.00	1.00
FORCE LEFT (Newtons)	4.32	1.51	5.36	12.77	0.08
FORCE RIGHT (Newtons)	8.85	9.68	6.32	17.98	0.48

Abbreviations

STD - Standard Deviation
Max - Maximum Difference Between Test Sessions
Min - Minimum Difference Between Test Sessions
Nm - Newton-meters
ROM - Range of Motion

ORDER OF TESTING

The control group was analyzed for differences between the side tested first and differences between the left and right sides for the fatigue index variable. The summary statistics are given in Table 4. Both groups tended to show less fatigue on the right. A two-way ANOVA with repeated measures on the left and right sides was performed for the fatigue index variable (Appendix C). Possible departure from normality was observed, therefore, the data was further analyzed nonparametrically. No significant differences were detected between the right or the left sides when analyzed with the Wilcoxon signed-ranks test for start side (Table 5). Start side (order of testing) was not considered for further data analysis.

TABLE 4. FATIGUE INDEX (% CHANGE) SUMMARY STATISTICS FOR THE CONTROL GROUP BY SIDE TESTED FIRST (N=15)

	Start Side	**N**	**MEAN**	**STD**	**MAX**	**MIN**
FATIGUE INDEX RIGHT	Right	6	2.48	11.75	14.62	-19.74
	Left	9	-1.47	28.27	36.57	-34.30
FATIGUE INDEX LEFT	Right	6	-2.49	16.75	19.30	-21.60
	Left	9	-3.71	11.11	16.81	-22.91

Abbreviations
N - Sample Size
STD - Standard Deviation
Max - Maximum
Min - Minimum

TABLE 5. WILCOXON SIGNED-RANKS TEST FOR THE DIFFERENCE BETWEEN FATIGUE INDEX LEFT AND FATIGUE INDEX RIGHT IN THE CONTROL GROUP (N=15)

START SIDE	N	MEDIAN DIFFERENCE	p-value
Start Right	6	1.89	p = 0.56
Start Left	9	17.35	p = 1.00

<u>Abbreviation</u>
N - Sample Size

<u>FATIGUE INDEX</u>

The fatigue index summary statistics within the three groups are given in Table 6. Both injured groups tended to show greater fatigue on the uninvolved side. The control group demonstrated less fatigue on the right. A two-way ANOVA with repeated measures on the left and right sides was performed (Appendix C). Possible departure from normality was observed, therefore, the data was further analyzed nonparametrically. No significant differences were found using the Wilcoxon signed-ranks test for differences between the right or the left sides within the three groups (Table 7). The fatigue index left variable was compared between the control and the injured right groups to determine significant differences between the groups. No significant differences ($p = 0.959$) were revealed using the Mann-Whitney U test (Appendix D).

TABLE 6. SUMMARY STATISTICS FOR FATIGUE INDEX (PERCENT CHANGE) BY GROUP (N=30)

	GROUP	N	MEAN	STD	MAX	MIN
FATIGUE INDEX LEFT	Right	11	-3.83	11.65	12.49	-22.93
	Left	4	2.17	36.79	56.29	-24.75
	Control	15	-3.22	13.08	19.30	-22.91
FATIGUE INDEX RIGHT	Right	11	-2.28	15.46	30.84	-32.61
	Left	4	-2.79	9.47	9.88	-12.75
	Control	15	0.11	22.58	36.57	-34.30

<u>Abbreviations</u>
N - Sample Size
STD - Standard Deviation
Max - Maximum
Min - Minimum

TABLE 7. WILCOXON SIGNED-RANKS TEST FOR THE DIFFERENCE BETWEEN FATIGUE INDEX RIGHT AND FATIGUE INDEX LEFT (N=30)

GROUP	N	MEDIAN DIFFERENCE	p - value
RIGHT INVOLVED	11	6.51	p = 0.46
LEFT INVOLVED	4	12.63	p = 0.88
CONTROL	15	1.92	p = 0.64

<u>Abbreviation</u>
N - Sample Size

The groups were further divided according to gender. The summary statistics are given in Table 8. No consistent trends were noted. A three-way ANOVA with repeated measures on the left and right sides was performed for the fatigue index variable (Appendix C). Normality could not be assumed, therefore, the data was further analyzed nonparametrically. No significant differences were found using the Wilcoxon signed-ranks test for differences between the right or the left sides for males or females within the three groups (Table 9). The small sample size for the involved left group precludes meaningful interpretation of the test.

TABLE 8. SUMMARY STATISTICS FOR FATIGUE INDEX (PERCENT CHANGE) BY GROUP AND GENDER (N=30)

	GROUP	GENDER	N	MEAN	STD	MAX	MIN
FAT. IND. RT.	RIGHT	FEMALE	5	3.56	16.07	30.84	-9.59
		MALE	6	-7.15	14.45	9.88	-32.61
	LEFT	FEMALE	2	-7.61	7.27	-2.47	-12.75
		MALE	2	2.04	11.09	9.88	-5.81
	CONT.	FEMALE	9	0.03	15.31	15.04	-28.28
		MALE	6	-0.17	32.45	36.57	-34.30
FAT. IND. LT.	RIGHT	FEMALE	5	-0.90	12.35	11.76	-19.95
		MALE	6	-6.28	11.56	12.49	-22.93
	LEFT	FEMALE	2	-20.24	6.39	-15.72	-24.75
		MALE	2	24.58	44.85	56.29	-7.14
	CONT.	FEMALE	9	-2.53	12.26	19.30	-14.67
		MALE	6	-4.25	15.38	16.81	-22.91

<u>Abbreviations</u>
N - Sample Size
STD - Standard Deviation
Max - Maximum
Min - Minimum
Fat. Ind. Rt. - Fatigue Index Right
Fat. Ind. Lt. - Fatigue Index Left
Cont. - Control Group

TABLE 9. WILCOXON SIGNED-RANKS TEST FOR THE DIFFERENCE BETWEEN FATIGUE INDEX RIGHT AND FATIGUE INDEX LEFT BY GENDER (N=30)

GROUP	GENDER	N	MEDIAN DIFFERENCE	p-value
RIGHT INVOLVED	FEMALE	5	1.52	p = 0.63
	MALE	6	7.83	p = 0.56
LEFT INVOLVED	FEMALE	2	12.63	NA
	MALE	2	-22.54	NA
CONTROL	FEMALE	9	1.92	p = 0.65
	MALE	6	10.85	p = 0.84

Abbreviation
N - Sample Size
NA - Not Applicable

PEAK TORQUE

The summary statistics for peak torque are given in Table 10. The peak torque left values were slightly greater for both injured groups. The control group had slightly greater peak torque values on the right. A two-way ANOVA with repeated measures on the left and right sides was performed (Table 11). The main effect group, and the interaction group x side were not significant. The main effect for side approached significance. The data was further analyzed with the paired t-test. No significant differences between the right or the left sides within the three groups were revealed (Table 12). The 95 percent confidence intervals for the mean differences for the three groups are given.

TABLE 10. SUMMARY STATISTICS FOR PEAK TORQUE BY GROUP (N=30)

	GROUP	N	MEAN	STD	MAX	MIN
PEAK TORQUE Left (Nm)	**Right**	11	38.53	4.62	47.80	33.60
	Left	4	38.55	8.11	48.00	31.40
	Control	15	34.76	4.50	40.20	26.20
PEAK TORQUE Right (Nm)	**Right**	11	36.38	4.09	41.40	29.80
	Left	4	35.40	4.97	39.40	28.60
	Control	15	35.25	4.47	42.60	27.00

Abbreviations
N - Sample Size
STD - Standard Deviation
Max - Maximum
Min - Minimum
NM - Newton-meters

TABLE 11. TWO-WAY ANALYSIS OF VARIANCE: EFFECT OF GROUP (SIDE INVOLVED) AND SIDE (LEFT OR RIGHT) ON PEAK TORQUE (N=30)

Source	df	SS	MS	F	p
Between Subjects					
Group	2	82.085	41.043	1.12	0.341
Error	27	988.408	36.608		
Total	29	1070.493			
Within Subjects					
Side	1	28.290	28.290	3.36	0.078
Side x Group	2	33.163	16.581	1.97	0.159
Error (Side)	27	227.413	8.423		
Total	30	288.866			

Abbreviations
df - Degrees of Freedom
SS - Sums of Squares
MS - Mean of Squares
F - *F* Statistic
p - p-value

TABLE 12. PAIRED t-TEST FOR THE DIFFERENCE BETWEEN PEAK TORQUE RIGHT AND PEAK TORQUE LEFT (N=30)

GROUP	N	MEAN DIFFERENCE (Nm)	95% CI
RIGHT INVOLVED	11	-2.15, p = 0.12	-4.97, 0.68
LEFT INVOLVED	4	-3.15, p = 0.28	-10.82, 4.52
CONTROL	15	0.49, p = 0.63	-1.64, 2.63

<u>Abbreviation</u>
N - Sample Size
CI - Confidence Interval

<u>TIME TO COMPLETE TEST</u>

The summary statistics for the time to complete the test are given in Table 13. The left and right values for the control group values were almost exact. The time to complete the test for the injured groups were longer on the involved side. A two-way ANOVA with repeated measures on the left and right sides was performed (Appendix C). Possible departure from normality was observed, therefore, the data was further analyzed nonparametrically. No significant differences were found using the Wilcoxon signed-ranks test for differences between the right or the left sides within the three groups (Table 14). The left time variables for the control and the injured right groups were analyzed to determine significant differences between the groups. The differences were not significant ($p = 0.716$) using the Mann-Whitney U test (Appendix D).

TABLE 13. SUMMARY STATISTICS FOR TIME BY GROUP (N=30)

	GROUP	N	MEAN	STD	MAX	MIN
TIME LEFT (SECONDS)	**Right**	11	41.40	6.40	54.60	30.51
	Left	4	45.70	16.99	56.52	20.44
	Control	15	41.90	5.10	49.56	34.00
TIME RIGHT (SECONDS)	**Right**	11	42.43	6.83	51.60	29.87
	Left	4	41.83	11.40	52.80	26.03
	Control	15	41.80	7.98	59.39	29.69

Abbreviations
N - Sample Size
STD - Standard Deviation
Max - Maximum
Min - Minimum

TABLE 14. WILCOXON SIGNED-RANKS TEST FOR THE DIFFERENCE BETWEEN TIME RIGHT AND TIME LEFT (N=30)

GROUP	N	MEDIAN DIFFERENCE	p-value
RIGHT INVOLVED	11	2.63	p = 0.90
LEFT INVOLVED	4	-4.27	p = 0.63
CONTROL	15	-2.16	p = 0.76

Abbreviation
N - Sample Size

EVERSION RANGE OF MOTION (ROM)

The summary statistics eversion ROM are given in Table 15. The injured groups tended to have greater ROM on the involved side. The control group had greater ROM on the left side. A two-way ANOVA with repeated measures on the left and right sides was performed for the eversion ROM variable (Appendix C). Normality could not be assumed, therefore, the data was further analyzed nonparametrically. The differences between the right and left sides within the three groups, when analyzed with the Wilcoxon signed-ranks test, were not significant (Table 16). The left eversion ROM variables were analyzed for differences between the control and the involved right groups using the Mann-Whitney U test (Appendix D). The differences were not significant ($p = 0.716$).

TABLE 15. SUMMARY STATISTICS FOR EVERSION RANGE OF MOTION (DEGREES) BY GROUP (N=30)

	GROUP	N	MEAN	STD	MAX	MIN
EVERSION ROM LEFT	Right	11	24.73	5.53	37.00	20.00
	Left	4	27.50	11.73	43.00	17.00
	Control	15	24.67	6.67	37.00	13.00
EVERSION ROM RIGHT	Right	11	25.64	7.98	42.00	15.00
	Left	4	24.75	8.54	33.00	14.00
	Control	15	21.73	7.76	36.00	10.00

Abbreviations
N - Sample Size
STD - Standard Deviation
Max - Maximum
Min - Minimum
ROM - Range of Motion

TABLE 16. WILCOXON SIGNED-RANKS TEST FOR THE DIFFERENCE BETWEEN EVERSION RANGE OF MOTION RIGHT AND EVERSION RANGE OF MOTION LEFT (N=30)

GROUP	N	MEDIAN DIFFERENCE (DEGREES)	p-value
RIGHT INVOLVED	11	-2.00	p = 0.93
LEFT INVOLVED	4	-5.50	p = 0.75
CONTROL	15	-4.00	p = 0.11

Abbreviation
N - Sample Size

MEAN PEAK FORCE

The summary statistics mean peak force are given in Table 17. Both injured groups tended to produce greater force on the left. The control group produced greater force on the right. A two-way ANOVA with repeated measures on the left and right sides was performed for the mean peak force variable (Appendix C). Possible departure from normality was observed, therefore, the data was further analyzed nonparametrically. No significant differences were found using the Wilcoxon signed-ranks test for differences between the right or the left sides within the three groups (Table 18). The involved right and the control groups were compared using the mean peak force left variable. The differences revealed using the Mann-Whitney U test (Appendix D) were not significant ($p = 0.299$).

TABLE 17. SUMMARY STATISTICS FOR MEAN PEAK FORCE BY GROUP (N=30)

	GROUP	N	MEAN	STD	MAX	MIN
MEAN PEAK FORCE LEFT (Newtons)	**Right**	11	139.37	13.16	160.22	115.60
	Left	4	144.89	27.57	181.72	119.49
	Control	15	131.34	19.66	159.18	100.20
MEAN PEAK FORCE RIGHT (Newtons)	**Right**	11	138.93	10.49	157.04	121.72
	Left	4	139.72	15.53	153.39	119.09
	Control	15	132.83	14.35	162.58	106.20

Abbreviations
N - Sample Size
STD - Standard Deviation
Max - Maximum
Min - Minimum

TABLE 18. WILCOXON SIGNED-RANKS TEST FOR THE DIFFERENCE BETWEEN MEAN PEAK FORCE RIGHT AND MEAN PEAK FORCE LEFT (N=30)

GROUP	N	MEDIAN DIFFERENCE (Newtons)	p-value
RIGHT INVOLVED	11	2.50	p = 1.00
LEFT INVOLVED	4	-2.93	p = 0.88
CONTROL	15	5.82	p = 0.64

Abbreviations
N - Sample Size

SPEARMAN RANK CORRELATION COEFFICIENTS

The intercorrelations of the variables analyzed in relation to FI are given according to group and extremity in Tables 19-22. All of the variables for the respective extremities in each group had little or no relationship.

The relationship of torque to power and work for the respective extremities were also analyzed for the involved right and control groups (Tables 23-26). The intercorrelations ranged from 0.673 - 0.781 on the left and 0.482 to 0.500 on the right for the involved right group. The intercorrelations for the control group ranged from 0.211 to 0.338 on the left, and from -0.016 to -0.700 on the right.

TABLE 19. SPEARMAN RANK CORRELATION COEFFICIENTS OF LEFT EXTREMITY VALUES FOR THE CONTROL GROUP (N=15)

Variable	1	2	3	4	5
1. Fatigue Index Left	1.00	0.14	-0.18	NA	NA
2. Peak Torque Left		1.00	-0.18	NA	NA
3. Time Left			1.00	NA	NA
4. Eversion ROM Left				1.00	0.11
5. Mean Peak Force Left					1.00

TABLE 20. SPEARMAN RANK CORRELATION COEFFICIENTS OF RIGHT EXTREMITY VALUES FOR THE CONTROL GROUP (N=15)

Variable	1	2	3	4	5
1. Fatigue Index Right	1.00	0.51	-0.15	NA	NA
2. Peak Torque Right		1.00	-0.35	NA	NA
3. Time Right			1.00	NA	NA
4. Eversion ROM Right				1.00	.08
5. Mean Peak Force Right					1.00

TABLE 21. SPEARMAN RANK CORRELATION COEFFICIENTS OF LEFT EXTREMITY VALUES FOR THE INVOLVED RIGHT GROUP (N=11)

Variable	1	2	3	4	5
1. Fatigue Index Left	1.00	-0.06	0.46	NA	NA
2. Peak Torque Left		1.00	0.18	NA	NA
3. Time Left			1.00	NA	NA
4. Eversion ROM Left				1.00	0.24
5. Mean Peak Force Left					1.00

TABLE 22. SPEARMAN RANK CORRELATION COEFFICIENTS OF RIGHT EXTREMITY VALUES FOR THE INVOLVED RIGHT GROUP (N=11)

Variable	1	2	3	4	5
1. Fatigue Index Right	1.00	-0.40	0.20	NA	NA
2. Peak Torque Right		1.00	-0.09	NA	NA
3. Time Right			1.00	NA	NA
4. Eversion ROM Right				1.00	0.25
5. Mean Peak Force Right					1.00

TABLE 23. SPEARMAN RANK CORRELATION COEFFICIENTS OF LEFT EXTREMITY VALUES FOR CONTROL GROUP

	Power Left	Work Left
Peak Torque Left	r=0.338, p=0.218	r=0.211, p=0.451

TABLE 24. SPEARMAN RANK CORRELATION COEFFICIENTS OF RIGHT EXTREMITY VALUES FOR CONTROL GROUP

	Power Right	Work Right
Peak Torque Right	r=-0.016, p=0.955	r=-0.700, p=0.815

TABLE 25. SPEARMAN RANK CORRELATION COEFFICIENTS OF LEFT EXTREMITY VALUES FOR INVOLVED RIGHT GROUP

	Power Left	Work Left
Peak Torque Left	r=0.673, p=0.023	r=0.781, p=0.005

TABLE 26. SPEARMAN RANK CORRELATION COEFFICIENTS OF RIGHT EXTREMITY VALUES FOR INVOLVED RIGHT GROUP

	Power Right	Work Right
Peak Torque Right	r=0.482, p=0.133	r=0.500, p=0.117

CHAPTER V

DISCUSSION

The primary purpose of this study was to determine if peroneal muscle fatigue was significantly greater in the involved extremity of subjects with unilateral functional ankle instability (FI) compared to the uninvolved extremity, and compared to a group of control subjects. The results of this study found no significant differences in the fatigue index of the involved and the uninvolved extremities of subjects with unilateral FI, or between the injured right and control groups. No significant order effect for the testing of the left and right extremities was observed.

One possible reason for the non-significant result is lack of the subjects giving their best effort at the start of the fatigue test. Failure to give full effort at the start of a fatigue test may result in a small fatigue index, or in some cases, show the subjects stronger at the end of the test. This potential flaw was documented by Patton (42), and discussed by Sinacore (51). The average repetition for the subjects to reach their peak torque in this study was number 18, with a range from 1-46.

Four subjects, one in the injured left group (subject 13) and four in the injured right group (subjects 5, 17, 18, & 19), demonstrated fatigue patterns exactly opposite of the

hypothesis. These subjects showed less fatigue on their injured side. Subject 19 reported having received physical therapy for the injury which included cycling, stretching, and theraband. This subject continues to use blue theraband daily for 50 repetitions. This might explain the increased resistance to fatigue on the involved side. The remaining three subjects reported not receiving physical therapy for the involved ankle. Subject 13 showed the largest difference for fatigue index between the involved and uninvolved sides, with a positive change of 56.29% on the involved side, and a negative change of 5.81% on the uninvolved side. Subjects 5, 13, and 17 used additional body motion during the test on the involved side, probably recruiting extra muscles, including the hamstrings, to facilitate performance. Lentell et al (31) proved testing ankle inversion/eversion with the knee flexed (loose packed) resulted in hamstring recruitment, and resulted in higher torque output than testing with the knee extended (closed packed).

The fatigue index was first studied in the quadriceps muscles (53). The authors noted in their study that individual susceptibility to fatigue varied and paralleled the fiber composition of the contracting muscles. There was a positive correlation between the fatigue index and the percentage of Type II muscle fibers. The same individual variability may account for the inconsistencies in the fatigue

index variables in this study. Also, the fatigue test used in this study probably was not the most appropriate test due to the high percentage of Type I fibers in the ankle evertors.

The fatigue index variable was also analyzed according to gender within the three groups. Initial analysis using the three-way ANOVA appeared to reveal some significant interaction between the groups and gender. Normality could not be assumed, therefore the data was analyzed nonparametrically for right and left differences within the groups for each gender. No significant differences were found. This supports Patton's (42) finding that isokinetic fatigue patterns are similar in men and women.

A secondary purpose of this study was to check test-retest reliability for ankle eversion on the Kin-Com. There are no published studies specific for ankle eversion on the Kin-Com. The fatigue index variable was the least reliable variable in the test-retest study. The retest value for the fatigue index left variable tended to be higher on the second test, while the retest value for the fatigue index right variable tended to be lower on the second test. All of the subjects reported kicking with their right foot on the questionnaire, and were labelled right leg dominant (64). The lower values for the right extremity on retest were opposite of what was expected with right dominant subjects.

The fatigue index variables also had the largest

standard deviations. When looking at the absolute values for these two variables, the smallest difference between the first and second tests was 1.75 percent units, and the largest difference was 33.97 percent units. This finding does not support the findings of Thorstensson (53), who reported no significant differences between testing sessions for fatigue index, and Sinacore (51), who reported high test-retest reliability coefficients for the percentage of torque decline at the end of a fatigue test. It must be noted that both of the studies performed fatigue tests on the knee extensors, and used a Cybex isokinetic dynamometer.

The mean peak force right variable also had a fairly large standard deviation, and large minimum and maximum differences between test sessions. The test-retest reliability appears to be greater with the remaining variables. The largest absolute difference between test sessions was for the time right, time left, and the mean peak force left variables. Subject #33 did not complete the 50 repetitions on the retest of the left extremity. This could account for a portion of the time variability. The peak torque left and right variables had the smallest absolute standard deviations for the differences between test sessions. The small amount of variability for peak torque test-retest reliability supports the results found in previous studies (27, 34).

Another secondary purpose was to determine if significant differences in peak torque, time to complete fatigue test, eversion ROM, and mean peak force could be detected in ankles with FI. No significant differences were detected between the FI and control groups, or within subjects for any of the variables. The finding of no significant strength deficits (peak torque) between the involved and uninvolved extremities in the FI group supports some previous studies (32, 33, 45), while it conflicts with another study (60). For the control group, the non-significant differences in strength between the dominant and nondominant sides confirms the findings by Wong (64).

None of the variables analyzed for association with FI appear to be related. The correlation of torque to work and power appears to be better correlated on the left side for the involved right group. The variations could relate to the subjects not giving their full effort during the test. The high correlation values of torque to work and power in the involved right group's left extremity support previous studies (40, 65).

LIMITATIONS OF THE STUDY

The design of this study includes the following limitations:

1. Small sample sizes (15 controls, 11 injured right, and 4

injured left). Further division of these groups by gender resulted in two cells with two subjects.

2. Fatigue index test not reliable.

3. No practice session to maximize effort on fatigue test.

4. Time between first and second test sessions for the six controls not consistent (average of 52.5 days). No reliability testing was performed on the FI group.

5. Isokinetic testing is not functional.

RECOMMENDATIONS FOR FURTHER STUDY

The following recommendations for further study are made based on the results limitations of this study. Larger sample sizes (at least double this study) are needed to increase the power of the study. Confidence interval computation for the nonparametric data was not feasible due to the small sample sizes.

The fatigue index test did not prove reliable for the ankle evertors at 180°/s. It is recommended to try the fatigue index test at various test speeds to determine if the test is reliable for the ankle evertors at different speeds. Recovery from fatigue described by Sinacore (50, 51) may prove to be more reliable with the ankle evertors. Although the recovery test most recently has been used to test quadriceps, this test was used in the 1960's to study strength recovery patterns following isometric and isotonic exercise in the

forearm flexors (9). The electrically elicited fatigue test developed by McDonnell et al (39) is another option. The test was proven reliable for measuring peripheral muscle fatigue in the quadriceps femoris muscle.

Conducting training sessions to familiarize subjects with the testing protocol should improve reproducibility of results. Use of ROM targets has been shown to improve reliability of torque output for ankle inversion and eversion (34). The twitch superimposition technique has been used to determine whether true maximal voluntary contractions are being performed (3, 44). Use of this technique during the training session would probably improve the validity of the fatigue results ensuring maximum effort with testing.

The time interval between testing sessions for test-retest reliability should be consistent. The average retest intervals range from 24 hours to eight days in the current literature (1, 7, 20, 27, 34, 39, 51, 62). It is recommended to perform the retest sessions one week after the initial test.

Isokinetic testing of the ankle evertors is not a functional method of testing. The results may not accurately predict how the muscles may react under conditions of normal activity and sport. Consideration of function must be given regarding future research on this topic.

CHAPTER VI

CONCLUSIONS

The results of this study do not support the hypothesis that fatigue might be a contributing factor to functional ankle instability (FI) as tested with using the fatigue index. The fatigue index, as described by Thorstensson (53), does not appear to be a reliable test for the ankle evertors on the Kin-Com isokinetic dynamometer at 180°/s. The protocol used does, however, appear to be reliable for measuring strength using peak torque values. Further study into fatigue and FI is needed.

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APPENDIX A

IRB #06787
11/02/95

UNIVERSITY OF OKLAHOMA HEALTH SCIENCES CENTER
College of Allied Health

Individual's Consent to Voluntary Participation in a Research Project

I, ________________________, voluntarily agree to participate in this study titled: Relationship of Peroneal Muscle Fatigue to Functional Ankle Instability, conducted by Mark Anderson, PhD. and Subrina Linscomb, P.T. This study is sponsored by the Department of Physical Therapy.

Purpose: I understand the purpose of this study is to determine if there is a connection between muscle fatigue (muscles in my ankle getting tired) and functional instability (repeated sprains or ankle giving way). I have been invited to participate because I have been diagnosed with repeated ankle sprains/ankle giving way or I am serving as a healthy volunteer.

Description of Study: I understand that if I agree to participate in this study, I will be given a questionnaire which will ask me general questions about my ankle injuries.

Next I will warm-up my ankles by riding a stationary bicycle at a comfortable pace for five minutes. I will pick a card to determine which ankle (injured or uninjured) will be tested first. I will tell the tester to set up either my left or right ankle (depending on which card I pick). I will not let the tester know if the ankle being tested in my injured or uninjured to keep her from testing the ankles differently.

The KinCom isokinetic dynamometer will be used to measure how fast my ankle muscles get tired. I will be tested at one specific, controlled speed of movement (180°/s). Seven repetitions will be performed to familiarize me with the speed of the machine and the resistance I will feel. Five repetitions will be at less than full effort and the last two will be at full effort. I will rest for three minutes before performing the fatigue test.

Next, I will perform repeated movements as hard and fast as I can until I am told to stop. I will be encouraged to work hard throughout the test. The test will be repeated on my other ankle. The testing session will last approximately 30 minutes.

I understand my picture may be taken once I am set up on the Kin-Com. The picture may be used to help explain the written description of how the test is set-up. I will not be able to be identified in any picture that may be used in a report or publication about this study.

Costs: I understand that I will not receive any charges or bills for participating in this study.

Risks: I understand the primary risk for participating in this study is the development of muscle soreness. If the soreness becomes severe, I will be removed from the study. I will be closely monitored for any unexpected side effects.

Benefits: I understand that participation in this study may result in me receiving an assessment of my muscle strength and how fast my muscles get tired. I understand that there are no other direct benefits to me as a subject in this study.

Compensation and Injury: If I am injured, medical treatment for the injury will be available to me, but I or my insurance carrier will be required to pay the usual fees for that treatment. I understand that no compensation will be available to me from the University of Oklahoma Health Sciences Center, unless I otherwise am covered by their health insurance or other employee benefits.

Subject's Assurances: I understand that my participation in this study is voluntary. I have not given up any of my legal rights or released any individual or institution from liability for negligence.

I understand that I may withdraw from this study at any time without penalty or loss of benefits to which I am otherwise entitled. My treatment by and the relations with the organizations involved in this study will not be affected now or in the future if I decide not to participate, or if I start the study and decide later to withdraw.

I understand that records of this study will be kept confidential, and that I will not be identifiable by name or description in any reports or publications about this study.

If I have questions about this study, or need to report any adverse effects from the research procedures, I will contact Dr. Mark Anderson at (405) 271-2131 during the day or Subrina Linscomb at (405) 670-1379. If I have questions about my rights as a research subject, I may contact the Director of Research Administration, in the OUHSC Office of Research

Administration, at (405) 271-2090.

I have read this consent document. I understand its contents, and I freely consent to participate in this study under the conditions described. I will receive a copy of this signed consent form.

Signature of Research Subject	Date
Signature of Witness	Date
Signature of Investigator	Date

APPENDIX B

Subject Questionnaire

Subject #   Age: Sex: ___Male   ___Female

Which foot do you prefer to kick with? (Circle One)   R   L

Ankle sprain subjects only

Involved Ankle: ___Left   ___Right

Number of Ankle Sprains (Total):

Number of sprains in Past 12 months:

Number of times ankle "gave way" in the past 12 months:

Approximate date of last sprain or episode of giving way:

Is the ankle painful now? (Circle One)   Y   N

Do you wear an ankle brace? (Circle One)   Y   N

If yes, during what activity?

Does the ankle give way during a certain time of day or during a certain point during activity? (Circle One)   Y   N

If yes, when?

Did you received physical therapy for the ankle? Y   N

If yes, briefly describe treatment.

APPENDIX C

ANALYSIS OF VARIANCE TABLES

TABLE 1. TWO-WAY ANALYSIS OF VARIANCE: EFFECT OF START (SIDE TESTED FIRST) AND SIDE (RIGHT OR LEFT) ON FATIGUE INDEX OF CONTROL GROUP (N=15)

Source	df	SS	MS	F	p
Between Subjects					
Start	1	47.855	47.855	0.15	0.709
Error	13	4261.375	327.798		
Total	14	4309.230			
Within Subjects					
Side	1	93.456	93.456	0.23	0.637
Start x Side	1	13.393	13.393	0.03	0.858
Error (Side)	13	5213.875	401.067		
Total	15	5320.724			

Abbreviations
df - Degrees of Freedom
SS - Sums of Squares
MS - Mean of Squares
F - *F* Statistic
p - p-value

TABLE 2. TWO-WAY ANALYSIS OF VARIANCE: EFFECT OF GROUP (SIDE INVOLVED) AND SIDE (LEFT OR RIGHT) ON FATIGUE INDEX (N=30)

Source	df	SS	MS	F	p
Between Subjects					
Group	2	53.115	26.557	0.09	0.918
Error	27	8351.073	309.229		
Total	29	8404.188			
Within Subjects					
Side	1	0.007	0.007	<1	0.997
Side x Group	2	108.450	54.225	0.16	0.855
Error (Side)	27	9261.684	343.025		
Total	30	9370.141			

Abbreviations
df - Degrees of Freedom
SS - Sums of Squares
MS - Mean of Squares
F - *F* Statistic
p - p-value

TABLE 3. THREE-WAY ANALYSIS OF VARIANCE: EFFECT OF GROUP (SIDE INVOLVED), GENDER, AND SIDE (LEFT OR RIGHT) ON FATIGUE INDEX (N=30)

Source	df	SS	MS	F	p
Between Subjects					
Group	2	35.387	17.694	0.07	0.937
Gender	1	398.051	398.051	1.47	0.237
Group x Gender	2	1843.741	921.871	3.40	0.050
Error	24	6506.830	271.118		
Total	29	8784.009			
Within Subjects					
Side	1	0.105	0.105	<1	0.987
Side x Group	2	110.877	55.438	0.15	0.858
Side x Gender	1	468.364	468.364	1.31	0.264
S x G x G	2	520.480	260.240	0.73	0.494
Error (Side)	24	8601.749	358.406		
Total	30	9701.575			

Abbreviations
df - Degrees of Freedom
SS - Sums of Squares
MS - Mean of Squares
F - *F* Statistic
p - p-value

TABLE 4. TWO-WAY ANALYSIS OF VARIANCE: EFFECT OF GROUP (SIDE INVOLVED) AND SIDE (LEFT OR RIGHT) ON TIME TO COMPLETE TEST (N=30)

Source	df	SS	MS	F	p
Between Subjects					
Group	2	24.742	12.371	0.12	0.886
Error	27	2748.474	101.795		
Total	29	2773.216			
Within Subjects					
Side	1	10.668	10.668	0.45	0.508
Side x Group	2	35.214	17.607	0.74	0.485
Error (Side)	27	639.182	23.673		
Total	30	685.064			

Abbreviations
df - Degrees of Freedom
SS - Sums of Squares
MS - Mean of Squares
F - *F* Statistic
p - p-value

TABLE 5. TWO-WAY ANALYSIS OF VARIANCE: EFFECT OF GROUP (SIDE INVOLVED) AND SIDE (LEFT OR RIGHT) ON EVERSION RANGE OF MOTION (N=30)

Source	df	SS	MS	F	p
Between Subjects					
Group	2	80.036	40.018	0.52	0.603
Error	27	2093.448	77.535		
Total	29	2173.484			
Within Subjects					
Side	1	27.962	27.962	0.80	0.380
Side x Group	2	50.454	25.227	0.72	0.496
Error (Side)	27	947.296	35.085		
Total	30	1025.712			

Abbreviations
df - Degrees of Freedom
SS - Sums of Squares
MS - Mean of Squares
F - *F* Statistic
p - p-value

TABLE 6. TWO-WAY ANALYSIS OF VARIANCE: EFFECT OF GROUP (SIDE INVOLVED) AND SIDE (LEFT OR RIGHT) ON MEAN PEAK FORCE (N=30)

Source	df	SS	MS	F	p
Between Subjects					
Group	2	996.213	498.107	1.21	0.314
Error	27	11131.620	412.282		
Total	29	12127.833			
Within Subjects					
Side	1	20.851	20.851	0.19	0.668
Side x Group	2	70.942	35.471	0.32	0.729
Error (Side)	27	3000.486	111.129		
Total	30	3092.279			

Abbreviations
df - Degrees of Freedom
SS - Sums of Squares
MS - Mean of Squares
F - *F* Statistic
p - p-value

APPENDIX D

MANN-WHITNEY U DATA TABLES

TABLE 6. MANN-WHITNEY U TEST FOR DIFFERENCES BETWEEN FATIGUE INDEX LEFT FOR CONTROL AND INJURED RIGHT GROUPS
$p = 0.959$

Group	N	Sum of Scores	Expected under H_o	Std under H_o	Mean Score
Control	15	204.0	202.50	19.27	13.60
Right	11	147.0	148.50	19.27	13.36

Abbreviations
N - Sample Size
H_o - Null Hypothesis
Std - Standard Deviation

TABLE 7. MANN-WHITNEY U TEST FOR DIFFERENCES BETWEEN TIME TO COMPLETE TEST LEFT FOR CONTROL AND INJURED RIGHT GROUPS
$p = 0.716$

Group	N	Sum of Scores	Expected under H_o	Std under H_o	Mean Score
Control	15	210.0	202.50	19.27	14.00
Right	11	141.0	148.50	19.27	12.82

Abbreviations
N - Sample Size
H_o - Null Hypothesis
Std - Standard Deviation

TABLE 8. MANN-WHITNEY U TEST FOR DIFFERENCES BETWEEN EVERSION ROM LEFT FOR CONTROL AND INJURED RIGHT GROUPS
$p = 0.716$

Group	**N**	**Sum of Scores**	**Expected under H_o**	**Std under H_o**	**Mean Score**
Control	15	210.0	202.50	19.22	14.00
Right	11	141.0	148.50	19.22	12.82

Abbreviations
N - Sample Size
H_o - Null Hypothesis
Std - Standard Deviation

TABLE 9. MANN-WHITNEY U TEST FOR DIFFERENCES BETWEEN MEAN PEAK FORCE LEFT FOR CONTROL AND INJURED RIGHT GROUPS
$p = 0.299$

Group	**N**	**Sum of Scores**	**Expected under H_o**	**Std under H_o**	**Mean Score**
Control	15	182.0	202.50	19.27	12.13
Right	11	169.0	148.50	19.27	15.36

Abbreviations
N - Sample Size
H_o - Null Hypothesis
Std - Standard Deviation

APPENDIX E

RAW DATA

ABBREVIATIONS

OBS	OBSERVATION
ID	IDENTIFICATION
AGE	AGE OF SUBJECT
GENDER	GENDER OF SUBJECT
INVOLVED	SIDE INJURED
START	SIDE FATIGUE TEST STARTED ON
FI_L	FATIGUE INDEX LEFT
FI_R	FATIGUE INDEX RIGHT
POWER_L	POWER LEFT
POWER_R	POWER RIGHT
WORK_L	WORK LEFT
WORK_R	WORK RIGHT
TORQUE_L	TORQUE LEFT
TORQUE_R	TORQUE RIGHT
TIME_L	TIME LEFT
TIME_R	TIME RIGHT
INJURY	SIDE INJURED
KICK	SIDE KICK WITH
INV_L	INVERSION RANGE OF MOTION LEFT
INV_R	INVERSION RANGE OF MOTION RIGHT
EV_L	EVERSION RANGE OF MOTION LEFT
EV_R	EVERSION RANGE OF MOTION RIGHT
ROM_L	RANGE OF MOTION LEFT
ROM_R	RANGE OF MOTION RIGHT
REPS_L	NUMBER OF REPETITIONS PERFORMED ON LEFT
REPS_R	NUMBER OF REPETITIONS PERFORMED ON RIGHT
FORCE_L	MEAN PEAK FORCE LEFT
FORCE_R	MEAN PEAK FORCE RIGHT
REP_PK_L	REPETITION PEAK FORCE REACHED LEFT
REP_PK_R	REPETITION PEAK FORCE REACHED RIGHT
SPRAINS	NUMBER OF ANKLE SPRAINS PAST 12 MONTHS
GIVE_WAY	NUMBER OF TIMES ANKLE "GAVE-WAY" PAST 12 MONTHS

CONTROL GROUP

OBS	ID	AGE	GENDER	START	FI_L	FI_R	POWER_L	POWER_R	WORK_L	WORK_R	TORQUE_L
1	2	29	1	0	-21.60	-19.74	13.84	15.40	362.87	423.69	39.0
2	4	25	0	0	12.70	14.62	15.00	20.49	333.91	380.69	40.2
3	7	38	1	1	-22.91	29.98	36.01	21.97	595.89	423.35	39.0
4	8	36	1	1	-0.41	19.42	22.13	24.24	570.55	505.22	32.8
5	9	23	1	1	16.81	-32.95	24.99	32.75	580.42	723.23	40.0
6	15	46	0	0	19.30	4.23	13.80	16.86	265.16	294.36	28.8
7	21	25	1	1	3.89	36.57	21.28	18.01	395.37	300.58	39.4
8	22	29	0	0	-14.49	5.25	13.85	16.28	354.01	491.62	33.8
9	27	26	0	1	-1.92	-22.32	7.41	11.58	159.59	205.19	37.4
10	28	36	0	0	-14.67	8.68	20.63	23.01	463.73	499.07	33.0
11	29	33	0	1	-6.53	15.04	18.21	20.19	363.73	467.41	32.4
12	31	27	1	1	-1.29	-34.30	20.67	22.88	404.58	392.44	37.0
13	32	37	0	0	3.81	1.81	14.13	15.48	255.39	374.49	33.4
14	33	37	0	1	-13.72	3.63	6.02	10.99	120.32	217.13	29.0
15	34	24	0	1	-7.28	-28.28	17.18	22.70	401.18	452.35	26.2

OBS	TORQUE_R	TIME_L	TIME_R	INJURY	INVOLVED	KICK	INV_L	INV_R	EV_L	EV_R	ROM_L	ROM_R
1	35.0	47.60	52.80	0	2	0	-21	-34	27	27	48	61
2	38.8	38.56	36.40	0	2	0	-17	-12	25	30	42	42
3	42.6	34.00	35.76	0	2	0	-16	-21	28	24	44	45
4	40.2	49.56	41.70	0	2	0	-30	-27	37	28	67	55
5	37.2	46.00	44.90	0	2	0	-32	-40	30	26	62	66
6	31.0	40.60	38.88	0	2	0	-14	-10	23	30	37	40
7	42.6	35.52	29.69	0	2	0	-21	-22	19	14	40	36
8	33.0	46.87	59.39	0	2	0	-15	-25	35	36	50	61
9	34.8	42.84	36.45	0	2	0	-13	-10	16	19	29	29
10	31.4	47.54	44.12	0	2	0	-32	-36	23	18	55	54
11	32.6	41.02	50.82	0	2	0	-21	-50	25	17	46	67
12	32.0	39.57	34.79	0	2	0	-29	-29	24	10	53	39
13	33.4	35.53	45.44	0	2	0	-23	-28	17	21	40	49
14	37.2	37.45	34.58	0	2	0	-15	-19	13	10	28	29
15	27.0	45.91	41.26	0	2	0	-33	-37	28	16	61	53

OBS	REPS_L	REPS_R	FORCE_L	FORCE_R	REP_PK_L	REP_PK_R
1	41	40	151.93	126.75	13	1
2	50	50	159.18	143.36	28	22
3	50	50	140.35	153.41	3	21
4	50	50	136.02	140.30	23	14
5	50	50	157.52	132.86	28	43
6	50	50	105.48	120.58	23	12
7	50	50	156.98	162.58	37	44
8	50	50	123.46	130.48	15	20
9	50	50	142.41	128.20	9	3
10	50	50	123.36	129.18	24	27
11	50	50	109.75	120.61	46	19
12	50	50	124.43	119.14	9	6
13	50	50	126.08	134.34	9	4
14	50	50	112.92	144.39	3	8
15	50	50	100.20	106.20	25	1

INJURED GROUP

OBS	ID	AGE	GENDER	INVOLVED	START	FI_L	FI_R	POWER_L	POWER_R	WORK_L	WORK_R
1	3	37	0	0	0	7.75	-9.59	12.48	13.10	239.68	296.26
2	5	28	0	0	1	11.76	30.84	15.11	19.42	463.94	521.04
3	6	22	0	1	1	-15.72	-2.47	13.37	13.90	368.13	303.91
4	10	25	1	0	1	12.49	-32.61	22.58	35.88	503.48	704.99
5	11	26	1	1	0	-7.14	9.88	21.52	24.36	543.16	632.07
6	12	55	0	0	0	-4.19	-6.92	11.39	16.98	226.11	438.99
7	13	40	1	1	0	56.29	-5.81	16.95	28.06	418.05	580.38
8	16	24	1	0	1	-11.91	-5.40	23.00	19.27	547.48	405.23
9	17	34	1	0	0	-4.32	9.88	34.26	25.04	759.31	631.99
10	18	27	0	0	1	-19.95	1.84	15.94	14.82	294.71	319.56
11	19	19	1	0	0	-6.44	2.71	22.03	30.36	353.39	489.66
12	20	44	0	1	0	-24.75	-12.75	8.33	15.46	90.22	178.28
13	23	26	1	0	0	-22.93	-8.79	23.00	26.27	476.23	550.64
14	26	18	0	0	0	0.13	1.65	12.20	17.50	307.00	308.33
15	35	24	1	0	1	-4.55	-8.68	27.87	23.73	534.45	367.64

OBS	TORQUE_L	TORQUE_R	TIME_L	TIME_R	INJURY	KICK	INV_L	INV_R	EV_L	EV_R	ROM_L	ROM_R
1	34.8	32.4	41.70	45.60	1	0	-11	-17	23	23	34	40
2	36.2	29.8	54.60	50.28	1	0	-22	-38	32	28	54	66
3	32.2	34.8	54.72	42.20	1	0	-5	-10	43	30	48	40
4	39.8	41.4	43.30	41.70	1	0	-28	-32	29	26	57	58
5	42.6	39.4	51.12	52.80	1	0	-35	-33	20	33	55	66
6	36.2	40.8	37.84	51.60	1	0	-7	-15	21	33	28	48
7	48.0	38.8	56.52	46.30	1	0	-16	-31	30	22	46	53
8	47.8	41.2	46.10	41.50	1	0	-27	-19	20	15	47	34
9	45.2	37.2	43.69	49.91	1	0	-45	-24	22	42	67	66
10	33.6	33.6	36.38	43.30	1	0	-6	-24	37	21	43	45
11	40.0	38.8	30.51	33.83	1	0	-13	-21	24	28	37	49
12	31.4	28.6	20.44	26.03	1	0	-14	-28	17	14	31	42
13	35.0	38.2	38.53	41.16	1	0	-32	-27	22	31	54	58
14	34.8	31.8	45.85	37.97	1	0	-35	-24	20	18	55	42
15	40.4	35.0	36.95	29.87	1	0	-24	-24	22	17	46	41

OBS	REPS_L	REPS_R	FORCE_L	FORCE_R	REP_PK_L	REP_PK_R	SPRAINS	GIVE_WAY
1	50	50	142.78	137.24	21	13	0	3
2	50	50	135.39	122.08	12	7	0	7
3	50	50	119.49	136.58	12	7	0	4
4	50	50	133.45	141.32	43	1	2	3
5	50	50	149.47	153.39	29	16	2	6
6	50	50	137.44	149.16	20	14	0	23
7	50	50	181.72	149.80	49	33	2	4
8	50	50	155.18	157.04	27	4	1	15
9	50	50	160.22	141.56	34	24	1	20
10	50	50	130.34	132.84	3	11	2	3
11	50	50	134.26	143.58	1	10	5	7
12	21	32	128.86	119.09	1	9	0	3
13	50	50	132.76	142.50	21	36	2	4
14	50	50	115.60	121.72	7	35	2	10
15	50	50	155.64	139.18	1	1	2	4

RETEST

SUB=1

OBS	FIRST	SECOND	ONE_TWO	ABSOLUTE
1	-0.41	33.56	-33.97	33.97
2	19.42	1.78	17.64	17.64
3	32.80	40.20	-7.40	7.40
4	40.20	35.60	4.60	4.60
5	49.56	46.83	2.73	2.73
6	41.70	41.97	-0.27	0.27
7	37.00	28.00	9.00	9.00
8	28.00	24.00	4.00	4.00
9	136.02	134.38	1.64	1.64
10	140.30	143.42	-3.12	3.12

SUB=2

OBS	FIRST	SECOND	ONE_TWO	ABSOLUTE
11	-14.67	-27.89	13.22	13.22
12	8.68	-20.59	29.27	29.27
13	33.00	38.00	-5.00	5.00
14	31.40	30.80	0.60	0.60
15	47.54	39.85	7.69	7.69
16	44.12	43.08	1.04	1.04
17	23.00	21.00	2.00	2.00
18	18.00	19.00	-1.00	1.00
19	123.36	124.73	-1.37	1.37
20	129.18	129.66	-0.48	0.48

SUB=3

OBS	FIRST	SECOND	ONE_TWO	ABSOLUTE
21	-6.53	4.15	-10.68	10.68
22	15.04	11.70	3.34	3.34
23	32.40	28.40	4.00	4.00
24	32.60	30.20	2.40	2.40
25	41.02	33.35	7.67	7.67
26	50.82	35.03	15.79	15.79
27	25.00	17.00	8.00	8.00
28	17.00	22.00	-5.00	5.00
29	120.61	111.27	9.34	9.34
30	109.75	127.73	-17.98	17.98

SUB=4

OBS	FIRST	SECOND	ONE_TWO	ABSOLUTE
31	-1.29	-11.42	10.13	10.13
32	-34.30	-23.76	-10.54	10.54
33	37.00	32.80	4.20	4.20
34	32.00	36.00	-4.00	4.00
35	39.57	38.16	1.41	1.41
36	34.79	34.82	-0.03	0.03
37	24.00	20.00	4.00	4.00
38	10.00	15.00	-5.00	5.00
39	124.43	123.72	0.71	0.71
40	119.14	128.14	-9.00	9.00

SUB=5

OBS	FIRST	SECOND	ONE_TWO	ABSOLUTE
41	3.81	14.99	-11.18	11.18
42	1.81	3.56	-1.75	1.75
43	33.40	36.60	-3.20	3.20
44	34.40	29.60	4.80	4.80
45	35.53	39.24	-3.71	3.71
46	45.44	38.13	7.31	7.31
47	17.00	26.00	-9.00	9.00
48	21.00	19.00	2.00	2.00
49	126.08	126.00	0.08	0.08
50	134.34	122.16	12.18	12.18

SUB=6

OBS	FIRST	SECOND	ONE_TWO	ABSOLUTE
51	-13.72	-9.55	-4.17	4.17
52	3.63	-3.78	7.41	7.41
53	29.00	31.20	-2.20	2.20
54	37.20	32.60	4.60	4.60
55	37.45	26.43	11.02	11.02
56	34.58	36.00	-1.42	1.42
57	13.00	22.00	-9.00	9.00
58	10.00	16.00	-6.00	6.00
59	112.92	125.69	-12.77	12.77
60	144.39	134.04	10.35	10.35